High-Resolution Wind Field Mapping in Support of the ONR Coupled Boundary Layer Air-Sea Transfer (CBLAST) Program

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LONG-TERM GOALS

The long-term goal of this research effort is to investigate the possibility of obtaining quantitative information about the near-surface wind field and perhaps other parameters that characterize the Marine Atmospheric Boundary Layer (MABL) from an analysis of Synthetic Aperture Radar (SAR) imagery. Because of its potential for yielding such information in the form of high-resolution imagery, this application of SAR, especially in coastal waters, would represent a significant advance over most scatterometer and passive microwave sensors that yield only coarse-resolution estimates of the wind field.

OBJECTIVES

Based on the results of effort over the past several years, we now believe that the possibility of generating high-resolution wind maps from SAR has been demonstrated. (This work was begun as part of an earlier ONR grant and more recently has been funded by NOAA/NESDIS as part of the Alaska SAR Demonstration Project.) In fact, our wind-map generation procedure has been automated so that high-resolution wind maps can be obtained from a SAR image within about 30 minutes after the raw image file is received at JHU/APL. Wind maps for the past several seasons may be accessed from our web site (http://fermi.jhuapl.edu/sar/stormwatch/ Click “RADARSAT Wind Fields”). The immediate objective of work on the present grant is to support the ONR-sponsored Coupled Boundary Layer Air-Sea Transfer (CBLAST) Program field experiments with SAR wind maps and daily Advanced High Resolution Radiometer (AVHRR) sea-surface temperature (SST) imagery. (Our AVHRR imagery may

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14. ABSTRACT
The long-term goal of this research effort is to investigate the possibility of obtaining quantitative information about the near-surface wind field and perhaps other parameters that characterize the Marine Atmospheric Boundary Layer (MABL) from an analysis of Synthetic Aperture Radar (SAR) imagery. Because of its potential for yielding such information in the form of high-resolution imagery, this application of SAR, especially in coastal waters, would represent a significant advance over most scatterometer and passive microwave sensors that yield only coarse-resolution estimates of the wind field.

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be found at http://fermi.jhuapl.edu/avhrr/ Click “CBLAST.”) These wind maps should provide valuable estimates of the spatial behavior of features within the MABL. Furthermore, comparison between the SAR-derived wind predictions and in situ and airborne data collected during the CBLAST field experiments will allow us to further refine our wind-mapping algorithms.

APPROACH

During 2000-2001, we have participated in various workshops in order to inform the other CBLAST researchers of our SAR wind mapping procedure, and to coordinate the SAR overpasses with planned aircraft and *in situ* measurements to be collected in CBLAST field experiments. For the CBLAST-low pilot experiment (conducted in mid-July to mid- August 2001), this coordination primarily involved researchers (PI: Jerry Crecscenti) at the NOAA Air Resources Laboratory (http://www.noaa.inel.gov/projects/cblast) who operate the LongEZ aircraft. This aircraft is equipped with various meteorological and other sensors to characterize the sea surface and the marine boundary layer. Coordination with the in situ measurements for the CBLAST-low pilot experiment involved primarily researchers at Woods Hole Oceanographic Institute (PI: Jim Edson) and at Rutgers (PI: Scott Glenn). When the processed SAR imagery and the airborne and in situ data from the pilot experiment become available, extensive inter-comparisons among these data sets will be begun.

Also during 2000-2001, we have continued the refinement of our wind-map generation procedure through comparisons with wind speed estimates from more conventional sources. In particular, we have compared our SAR wind maps with coincident wind speed estimates from NASA’s QuikSCAT scatterometer [Spencer et al., 2000] collected within a few-hour time window over the same region. The close agreement between these two measurements strongly suggests that the use of QuikSCAT wind directions in the SAR inversion process could ultimately lead to a robust operational technique for high-resolution coastal wind speed mapping.

WORK COMPLETED

- We have coordinated the collection of RADARSAT imagery with in situ and airborne measurements to support the CBLAST-low pilot experiment conducted from mid-July to mid-August 2001 off the south coast of Martha’s Vineyard, MA. A web page that gives a brief discussion of our SAR wind mapping effort and particularly the coordination of this work with CBLAST-low experiment is located at the URL: http://fermi.jhuapl.edu/CBLAST/. Twelve overpasses in the wide ScanSAR beam mode have been collected between the dates of July 21 and August 15, 2001. Click “Overpasses; 2001” on the above page for more details.

- We have compiled a database containing all the QuikSCAT wind measurements collected within a 6-hour time widow of our SAR wind maps in the Gulf of Alaska for the year 2000, and completed a statistical comparison between the SAR and QuikSCAT wind estimates.

- Our web site at: http://fermi.jhuapl.edu/sar/stormwatch/ contains near real-time wind fields and QuikSCAT comparisons. Click “RADARSAT Wind Fields” or “Comparison with QuikSCAT.”

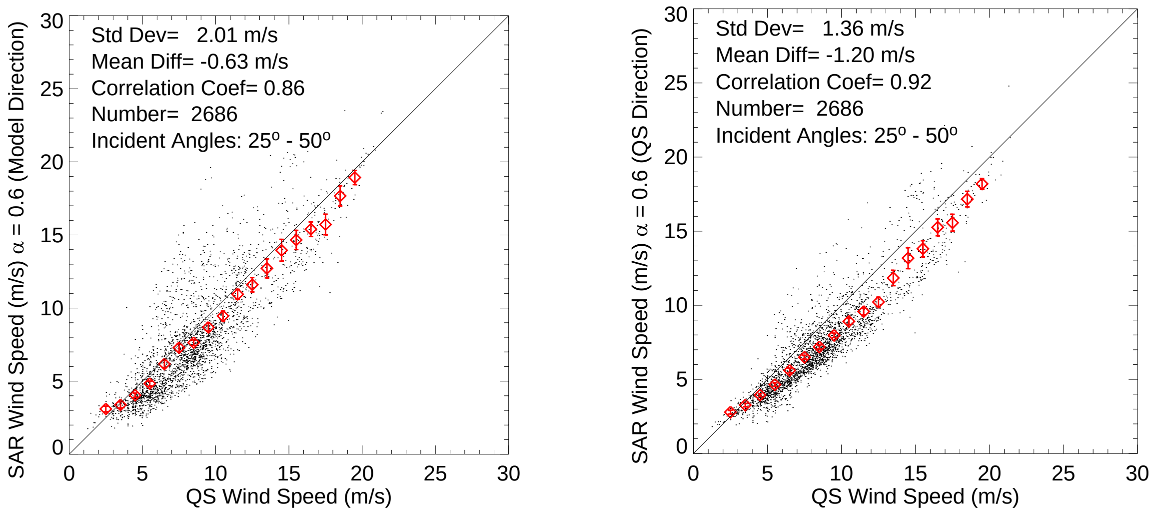

Fig. 1: Scatter plot of SAR-derived versus QuikSCAT wind estimates for all cases in our SAR image database for which the time separation between the two estimates was less than 15 minutes and the SAR incidence angle was between 25° and 50°. The SAR wind estimates in the left panel were extracted using the NOGAPS model directions while those in the right panel were extracted using the QuikSCAT directions. A value of α = 0.6 was used for the wind inversion in both panels.

RESULTS

We have compiled a database containing all of the QuikSCAT wind measurements collected within a 6-hour time widow of RADARSAT-1 SAR imagery in the Gulf of Alaska for the year 2000. This database contains over 58,000 individual QuikSCAT wind estimates. In Fig. 1, we show scatter plots of SAR-derived wind speeds versus the corresponding QuikSCAT values for all cases in the database for which the time separation between the two measurements is less than 15 minutes. The SAR-derived wind speeds in this plot were averaged over a 25-kilometer square area to conform to the nominal QuikSCAT resolution [Spenser, et al, 2000]. The red diamonds in the figure indicate the average SAR-derived wind speed over 1 m/s QuikSCAT wind intervals centered as indicated. The error bars on the diamonds show the 90% confidence level for each interval. As noted in the figure, the standard deviation of the difference between the SAR and the QuikSCAT wind speeds is 2.01 m/s when the NOGAPS wind directions are used (left panel), and drops dramatically to only 1.36 m/s when the QuikSCAT wind directions are used in the SAR wind inversion (right panel). This improvement is probably not too surprising given the fact that the 25 km resolution of the QuikSCAT wind directions is significantly higher than the 1°×1° grid spacing available for the model wind directions. Perhaps a more surprising feature shown in Fig. 1 is that the (magnitude) mean difference between the SAR and QuikSCAT wind speeds is about twice as large when the QuikSCAT wind directions are used.

The RADARSAT-1 SAR operates at C-band, but it transmits and receives horizontally-polarized (HH-pol). One of the most commonly used scatterometer algorithms for C-band is the CMOD4 algorithm [Stoffelen and Anderson, 1997] developed for use on the ERS-1/2 scatterometer that operated at C-band vertical polarization (VV-pol).

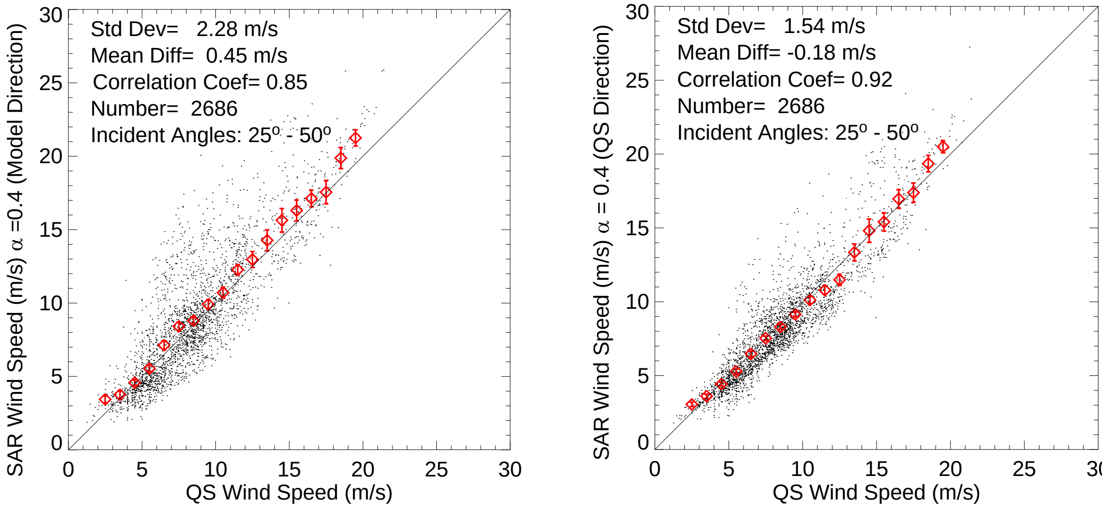

Fig. 2: Scatter plot of SAR-derived versus QuikSCAT wind estimates for all cases in the SAR image database for which the time separation between the two estimates was less than 15 minutes and the SAR incidence angle was between 25º and 50º. The SAR wind estimates in the left panel were extracted using the NOGAPS model directions while those in the right panel were extracted using the QuikSCAT directions. A value of α = 0.4 was used for the wind inversion in both panels.

The CMOD4 algorithm has been validated during numerous experimental campaigns for incident angles in the range from about 20º to 60º. Unfortunately, there is no validated scatterometer algorithm that relates the HH-pol normalized radar cross section (NRCS) of the RADARSAT-1 SAR to wind. To deal with this deficiency, we employ a polarization ratio following the development of Thompson et al. [1998]. This development relates the HH-pol NRCS, σ_0^{H}, to the VV-pol NRCS, σ_0^{V}, through the equation

$$\sigma_0^{\mathrm{H}} = \frac{\left(1+\alpha\tan^2\theta\right)^2}{\left(1+2\tan^2\theta\right)^2}\sigma_0^{\mathrm{V}}, \tag{1}$$

where σ_0^{V} is the NRCS predicted by the CMOD4 algorithm and contains all the wind vector dependence. Thompson et al. [1998] proposed a value of $\alpha = 0.6$ in Eq. 1 based on airborne measurements of the C-band HH-pol NRCS collected at several incident angles and a range of wind speeds by Unal et al. [1991]. For the SAR wind speed retrievals shown in Fig. 1 above, we have chosen a value of $\alpha = 0.6$ in Eq. 1. Besides the HH-pol airborne measurements [Unal et al., 1991] that indicate a value of $\alpha = 0.6$, this value is also consistent with comparisons between SAR-derived wind speeds and both NOGAPS model and NDBC buoy estimates [Monaldo et al., 2001].

With the above discussion of the α parameter in mind, we can return to our discussion of bias in the scatter plots shown in Fig. 1. From the form of Eq. 1, one can see that for fixed wind conditions and radar geometry, σ_0^{H} increases with increasing α. Since σ_0^{V} is a monotonically increasing function of the wind speed (through CMOD4), a lower value of α must be balanced by an increased wind speed in Eq. 1 to keep σ_0^{H} constant. Thus, a slight reduction of α in the SAR wind inversion should lower the magnitude of the bias in the mean wind difference in Fig. 1. This is, in fact, the case as illustrated in

Fig. 2 where we show the same scatter plots of the SAR-derived versus QuikSCAT wind estimates as in Fig. 1, but with a value of $\alpha = 0.4$ in the SAR inversion equations. As before, we find that the standard deviation of the difference is more than 30% lower when the QuikSCAT wind directions are used. However, using $\alpha = 0.4$ we find that the (magnitude) mean difference is reduced for both cases, and in fact is nearly eliminated (–0.18 m/s) when the QuikSCAT wind directions are used.

The results shown in Fig. 2 suggest that a more accurate SAR wind inversion might be obtained using $\alpha = 0.4$ instead of $\alpha = 0.6$ as indicated by the data of Unal et al. [1991]. We believe the uncertainties inherent in our wind inversion process preclude a determination of the α to an accuracy better than about ±0.2 or so. A value somewhat lower than 0.6 would, however, be more in line with theoretical predictions from state-of-the-art rough-surface scattering models that include the effects of long-wave tilt and hydrodynamic modulation [Romeiser et al., 1997]. Such models generally predict C-band polarization ratios corresponding to rather smaller α-values. In any case, it is clear that present knowledge of the C-band polarization ratio is inadequate. The ENVISAT ASAR, to be launched early in the fall of 2001, will have the capability to collect virtually simultaneous dual-polarization SAR images covering a wide range of incidence angles [Attema et al., 2000]. We believe that this imagery when coupled with accurate environmental characterization will offer a unique opportunity to improve our understanding of the polarization-ratio discrepancy discussed above, and to ultimately improve the SAR wind inversion process.

IMPACT/APPLICATIONS

The operational need for high-resolution wind maps is urgent. The primary application users for the products and techniques produced by this work are government agencies tasked with coastal marine weather forecasting, natural resource protection and management , and those charged with safety and law enforcement in coastal areas. From a scientific standpoint, SAR-derived high-resolution wind maps provide the first opportunity to study the spatial variability of the surface wind field over an extended area at resolutions of a few hundred meters. Knowledge of wind variability at these scales is important for understanding the effect of rapid changes in the surface boundary conditions, caused for example by sharp variations in the local topography or surface temperature, on the near-surface circulation.

TRANSITIONS

As part of the Alaska SAR Demonstration phase of the NOAA StormWatch Program, we have been supplying SAR wind maps in near real time to meteorologists in Alaska as a forecasting aid in this topologically-complicated region.

RELATED PROJECTS

NOAA/NESDIS is currently funding the applications-oriented portion of our SAR wind mapping effort under the auspices of ONR.

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